

# CEMENT AND CEMENT MANUFACTURE

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## Standard Specifications for Portland Cement.

### SUGGESTED NEW TESTS.

THE subject of standard specifications was dealt with at some length by Prof. Dr. Hans Kühl in a recent number of *Zement*. He pointed out that cement is used for such a variety of types of construction nowadays that a single specification cannot cover the requirements of all users. Already special specifications have been issued by various concerns; for instance, the cement used for the Hoover Dam is required to have a particularly low evolution of heat.

Strength, shrinkage, rise of temperature, and chemical resistance are the characteristics of cement which should be considered for practical application. If these four divisions are accepted, the problem is limited to the production of four types of cement in each of which one of the above characteristics is emphasised and the others possessed only in so far as they are in accord with the requirements of the basic type.

One type of cement would correspond approximately to rapid-hardening Portland cement, whose outstanding characteristics would be quick hardening, high strength, and complete freedom from unsoundness. It would not need to conform to very severe requirements in such properties as shrinkage, rise of temperature, density, and the like. A cement of this type would correspond to the Swedish "building construction" cement and would be specially suited to reinforced concrete construction.

The most important characteristic of another type would be very small tendency to shrink. A cement with low shrinkage is urgently needed for the construction of concrete roads. We have little experience of shrinkage tendencies, although it seems that the chemical composition, besides fineness and percentage of water, plays a special part. According to American investigations<sup>1</sup> cements low in silica and high in alumina and iron content have a low shrinkage, as have cements of the so-called Kühl-cement type (bauxite cement).

A third type of cement would have a low evolution of heat, suitable for mass concrete work.

A fourth type of cement would have a high chemical resistance. The density of concrete is more important in preventing corrosion than the chemical composition of the cement used, hence cements should be included in this class which either approximate to ore cement or have a specially high resistance due to the addition of materials such as trass.

The properties which should be tested are fineness, setting time, soundness, and strength, but the methods of doing this need to be changed. Sieve data are not sufficient for a clear idea of the fineness of a cement. It is necessary to divide the material into at least three fractions, coarse, medium, and fine. It has been shown<sup>2</sup> to<sup>7</sup> that the distribution of sizes of particles in cement follows a simple exponential law and that by determining a few points on the fineness curve a complete picture of the size distribution can be gained. If  $R$  is the amount of any particular fraction of diameter  $x$  (in microns), then according to Rosin and Rammler

$$R = 100 \cdot e^{-bx^n}$$

where  $e$  is the base of natural logarithms and  $b$  and  $n$  are constants depending on the type of cement. These two constants can be calculated by determining the amounts of two fractions of different diameters. There are a number of methods of particle size analysis, such as the pipette analysis of Andreasen<sup>8</sup>, the air elutriator of Gonell<sup>9</sup>, the sedimentation analysis of Kühl and Czernin<sup>10</sup>, and the optical method.<sup>11</sup>

Methods of testing for setting time other than with the Vicat needle are needed, and may be found in the measurement of the heat development during setting, the electrical conductivity, or the electromotive force developed by an element when the cement paste forms the second electrode. In the case of heat development the results obtained in the laboratory cannot be directly applied to practice unless a method of testing the mortar or concrete is evolved, for the processes occurring in a small pat of neat cement are somewhat different from those in a mass of concrete. The setting test where the change with respect to time is measured, and Guttmann's<sup>12</sup> method of testing the static lateral pressure in a mass of mortar, show promise of good results.

Until lately soundness has been tested only from the point of view of expansion. In the new Swiss specification shrinkage is also taken into account, and special attention should be given to this. Expansion of cement can be easily overcome since we now know it is due to free lime which can be accurately determined by analysis. The Le Chatelier test is suitable for measuring expansion; it does not, however, show the expansion due to calcium sulphate and magnesia, and limits for these are needed. In the case of shrinkage, it is necessary to distinguish between reversible and irreversible shrinkage. The specimen for this test should not be so small as to make measurements difficult or so large that equilibrium with the surrounding atmosphere will be attained too slowly. It will be necessary to regulate the temperature and humidity of the surrounding atmosphere.

The importance of compressive strength has been over-emphasised. The most important factor is the tensile strength at 28 days (water curing), but compressive strength should also be kept in mind. When the conditions of testing are suitable (as, for instance, in the Swiss specification with Haegermann's mixed sand) the compressive strength can be calculated from the tensile strength by the formula  $Z = 1.2 D^{2/3}$ , where  $Z$  is the tensile strength and  $D$  the compressive strength. This applies only to normal silicate cements. It should be noted that both the tensile and compressive strengths can be obtained from the bending test.

The time has come to abandon earth-moist mortars for testing purposes and to adopt plastic mortars which give results of more practical value, for it is under such conditions that cement is used. The behaviour of cements gauged with increasing amounts of water will have to be noted, because a cement with normal properties with the usual water-cement-ratio may be of little use when used with a high water-cement-ratio. It seems advisable to use a sand so graded that a high water-cement-ratio can be used and at the same time a plastic mortar obtained. It may also be necessary to alter the proportion of sand to attain this object.

Combined air and water curing should be superseded by water curing since the former does not so much give the strength of the cement as afford a figure for the extent of drying out of the specimen. In brief, it seems that the strength tests should be directed at obtaining the compressive and bending strengths (possibly the impact bending test also) on plastic mortars with the highest possible water-cement-ratio cured under water for at least 28 days.

The modulus of elasticity is often of importance, as in the case of road construction. It can be calculated sufficiently accurately for normal cements from the formula  $E = k\sqrt{ZD}$  where  $E$  is the modulus of elasticity,  $Z$  the tensile strength,  $D$  the compressive strength, and  $k$  a constant. It has been found by Werner and Giertz-Hedström<sup>13</sup> that the tendency to form cracks is least when a high tensile strength is combined with a low modulus of elasticity.

The development of heat would need to be determined by the "heat of solution" method. The heat of solution is measured before and after hydration by dissolving the material in a mixture of hydrofluoric and nitric acids, the difference between the two values giving the heat liberated on hydration. The other methods used for attaining this object are not suited to practice.

A test for the resistant properties of cement is difficult to find since it depends largely on the density of the concrete and the method of preparation. A process which entails the examination of the behaviour of concrete when water or corrosive solutions are forced through it shows promise<sup>14</sup>.

It is preferable to place an upper limit on the lime content rather than a lower one, and this should be combined with a limit for the allowable free lime content.

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- <sup>13</sup> H. Kühl, *Zement* 14, 1 (1925).
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## Heat Transmission in Rotary Kilns.—IX.

By W. GILBERT, Wh.Sc., M.Inst.C.E.

(181) It is now proposed to study the effect of variations in the kiln diameter and in the charge per cent. on the rate of heat transmission to the material inside the kiln. To this end calculations are made for three of the stages, or subdivisions of the kiln, which are considered to be representative. The information obtained has a direct bearing on the design of rotary kilns of the usual type, and in addition it makes clear the advantages and disadvantages of kilns provided with exceptionally large-diameter zones for drying slurry and for clinkering. In each representative stage wide changes are assumed to occur in the kiln diameter and in the charge per cent., but the flame, gas, and material temperatures, and the gas composition and velocity, are assumed to be similar to those of the corresponding stage in the 400-ft. kiln (see Part VI), hence most

TABLE XXVII.  
Preliminary data for stage (10).  
Diameter variable—charge 6 per cent.

I	KILN DIAMETER IN FEET	2	4	6	8	11	15
2	Area of cross section, less charge sq. ft.	2.95	11.82	26.57	47.27	89.38	166.1
3	Equivalent kiln diameter ft.	1.94	3.88	5.82	7.76	10.66	14.54
4	Gas velocity ft. per second	26.6	26.6	26.6	26.6	26.6	26.6
5	Convection Gas and lining	1.51	1.32	1.26	1.26	1.26	1.26
6	Constants $H_c$ Gas and material	1.65	1.44	1.38	1.38	1.38	1.38
7	Values for $H_c$	0.125	0.25	0.37	0.50	0.68	0.93
8	of P.D. for $H_2O$	0.44	0.88	1.32	1.77	2.43	3.31
9	Density factor for coke particles, F.	0.19	0.35	0.47	0.57	0.69	0.80
10	Storage factor for kiln lining	0.75	0.75	0.75	0.75	0.75	0.75

of the figures required for calculation purposes can be obtained from data already published. The standard coal consumption is 24.5 per cent. in all cases.

(182) Attention is first given to stage (10) in which the first half of the  $CaCO_3$  is decomposed, and it is required to determine (1) the result of varying the kiln diameter from 2 ft. to 15 ft. when the charge remains constant, and (2) the result of varying the charge from 3 per cent. to 25 per cent. when the kiln diameter remains constant.

### Diameter Variable—Charge 6 per cent.

Proceeding with the first part of the enquiry, in which the diameter is variable, some of the working conditions for stage (10), as taken from Part VIII, are reproduced below.

- (a) Flame temperature .. .. .. 2,450 deg. F.
- (b) Average gas temperature .. .. .. 2,300 deg. F.
- (c) Average material temperature .. .. .. 1,400 deg. F.
- (d) Gas velocity .. .. .. 26.6 feet per second.
- (e) Average gas composition  $H_2O$  .. .. 6.42 per cent.
- (f) by volume  $CO_2$  .. .. 22.75 per cent.

(183) Calculations of heat transmission are made for kiln diameters of 2, 4, 6, 8, 11, and 15 ft. respectively, the charge being 6 per cent. in all cases. Preliminary data is given in Table XXVII.

(184) In lines (2) and (3) of Table XXVII the reduction of the kiln area in cross section due to the volume occupied by the charge of 6 per cent. is taken into account. It is now necessary to do so since calculations made later deal with charges up to 25 per cent.

Line (4).—The gas velocity listed for stage (10) of the 400-ft. kiln was 25 ft. per second. Deducting the area in cross section occupied by the 6 per cent. charge it becomes 26.6 ft. per second, and this value is used in all calculations which relate to stage (10).

Lines (5) and (6).—The values of  $Hc$  are based on the gas velocity in line (4), on the average lining temperature in the upper arc as finally calculated, and on the material temperature of 1,400 deg. F. For further details see Table VI, and paras. (38) to (40).

Lines (7) and (8).—The  $P.D.$  values for use with the tables of gas radiation given in Part II are based on the gas composition by volume, see para. (182), and on the equivalent kiln diameters given in line 3.

Line (9).—Values of  $F$  are calculated as in para. (159), line 11. The diameter used in each case is that given in line 3.

Line (10).—For stage (10) of the 400-ft. kiln the storage factor was found to be 0.75, and this value is used with small error for each diameter of kiln listed.

It will be remembered that in stage (10) the heat transmission is mainly by flame radiation, but the heat transmitted by gas radiation and by convection cannot altogether be neglected.

(185) An equivalent ring 1 ft. wide is now taken at the centre of the stage, and calculations are made of the rate of heat transmission to it in B.T.U. per minute for each diameter listed in Table XXVII, the charge being 6 per cent. The result is shown by Fig. 31 in which the base line represents the kiln diameter in feet. The material receives heat in three ways; each quantity is shown separately on the graph. The heat transmitted to the kiln lining and subsequently lost in shell radiation is also shown.

As the kiln diameter increases the heat transmitted from the flame (or the incandescent coke particles) to the material chord is seen to be of most importance. Next in order comes the heat transmitted from the kiln lining to the underside of the material. The heat radiated from the kiln lining to the material chord falls off as the diameter increases since it has to pass through the incandescent coke particles and the gas.

The shell radiation [which was 811 B.T.U. per foot run per minute for stage (10) of the 400-ft. kiln where the diameter is 10.2 ft.] is assumed to be proportional to the diameter throughout.

(186) The total heat transmitted per foot run for any kiln diameter is found by adding the ordinates of the four curves on Fig. 31. To obtain the heat transmission (a) per cubic foot of kiln volume or (b) per square foot of lining surface

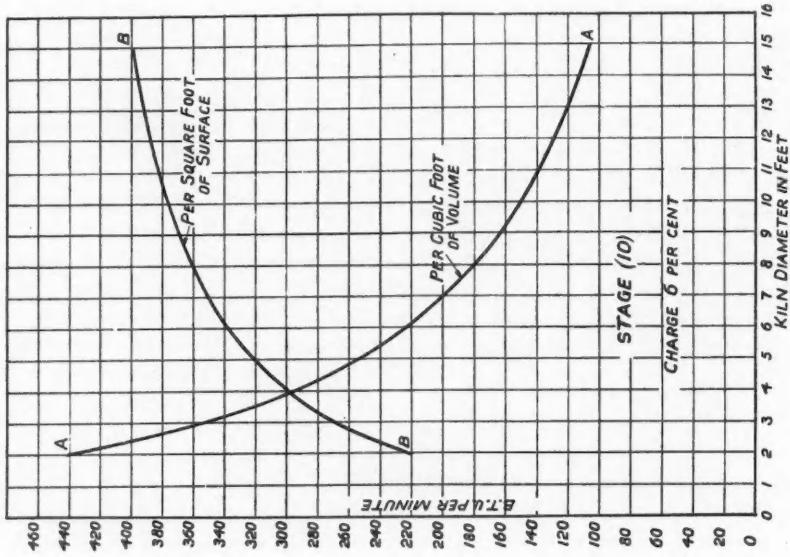


Fig. 32.

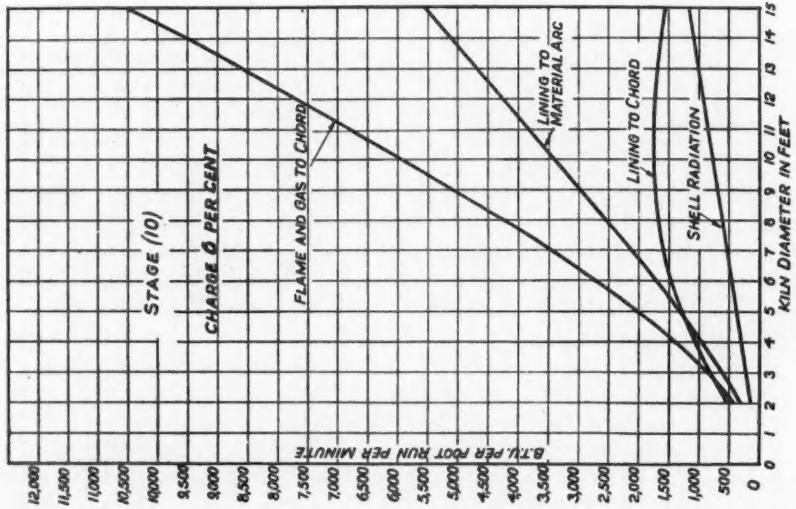


Fig. 31.

it is necessary to divide the total heat transmission by the volume of the equivalent ring, which is  $\frac{\pi}{4} D^2$ , or by its surface area which is  $\pi D$ , where  $D$  is the inside diameter in feet.

The result is shown on Fig. 32, in which the base line again represents the kiln diameter in feet. The ordinates to curve *AA* show for stage (10) the rate of heat transmission in B.T.U. per cubic foot of kiln volume per minute, and the ordinates to curve *BB* give the rate of heat transmission in B.T.U. per square foot of lining surface area per minute.

(187) Curve *BB* shows that for small diameters the rate of heat transmission per square foot of surface area increases rapidly as the diameter is increased, but a value nearly uniform is ultimately obtained.

TABLE XXVIII.  
Preliminary data for stage (10).  
Charge variable—diameter 10.2 feet.

<i>1</i>	<i>CHARGE IN KILN PER CENT</i>	<i>3</i>	<i>5</i>	<i>10</i>	<i>15</i>	<i>20</i>	<i>25</i>
<i>2</i>	<i>Area of cross section, less charge</i> sq. ft.	<i>79.26</i>	<i>77.62</i>	<i>73.54</i>	<i>69.45</i>	<i>65.37</i>	<i>61.28</i>
<i>3</i>	<i>Equivalent diameter of kiln</i> ft.	<i>10.04</i>	<i>9.94</i>	<i>9.68</i>	<i>9.40</i>	<i>9.12</i>	<i>8.83</i>
<i>4</i>	<i>Gas velocity</i> ft. per second	<i>26.6</i>	<i>26.6</i>	<i>26.6</i>	<i>26.6</i>	<i>26.6</i>	<i>26.6</i>
<i>5</i>	<i>Convection</i> Gas and lining	<i>1.24</i>	<i>1.24</i>	<i>1.25</i>	<i>1.25</i>	<i>1.26</i>	<i>1.26</i>
<i>6</i>	<i>Constants</i> <i>Hc</i> Gas and material	<i>1.38</i>	<i>1.38</i>	<i>1.38</i>	<i>1.38</i>	<i>1.38</i>	<i>1.38</i>
<i>7</i>	<i>Values of</i> <i>F</i> for <i>H<sub>2</sub>O</i>	<i>0.64</i>	<i>0.64</i>	<i>0.62</i>	<i>0.60</i>	<i>0.59</i>	<i>0.57</i>
<i>8</i>	<i>P.D.</i> for <i>CO<sub>2</sub></i>	<i>2.28</i>	<i>2.26</i>	<i>2.20</i>	<i>2.14</i>	<i>2.07</i>	<i>2.01</i>
<i>9</i>	<i>Density factor for coke particles, F</i>	<i>0.67</i>	<i>0.67</i>	<i>0.66</i>	<i>0.65</i>	<i>0.63</i>	<i>0.62</i>
<i>10</i>	<i>Storage factor for kiln lining</i>	<i>0.74</i>	<i>0.75</i>	<i>0.75</i>	<i>0.74</i>	<i>0.73</i>	<i>0.72</i>

From curve *AA* it is seen that the rate of heat transmission per cubic foot of volume falls rapidly as the diameter increases. It has proved useful in the past to assume that the output of a kiln would be sensibly proportional to its volume, but with some falling off as the diameter increased. The rule was usually applied to kilns where the average diameter ranged from 6 to 8 ft., and curve *AA* shows that within these limits the variation in the case of stage (10) is not excessive. The corresponding figures for other stages will be given later. By taking a wide range of kiln diameters, however, curve *AA* shows clearly that the output of a rotary kiln has no real relation to its volume.

#### Diameter 10.2 feet—Charge Variable.

(188) Continuing with Stage (10), in which the first half of the  $\text{CaCO}_3$  is decomposed, the next step is to find the effect of varying the charge from 3 per cent. to 25 per cent. when the diameter remains constant.

A diameter of 10.2 ft. [which is that of stage (10) of the 400-ft. kiln] is first assumed. The data necessary for calculation purposes is given in para. (182) and in Table XXVIII. The equivalent diameters given in line 3 of Table XXVIII correspond to the areas given in line 2, and these diameters are used as before to calculate the *P.D.* values for gas radiation in lines 7 and 8 and the values of *F* in line 9.

(189) An equivalent ring 1 ft. wide is again taken at the centre of the stage, and calculations in detail of the heat transmitted to it are made for each of the six charges listed in Table XXVIII. On dividing the total heat transmitted in each case by  $10.2 \pi$  the heat transmitted per square foot of lining surface area per minute is obtained.

The result is shown on Fig. 33 and by line *AA*. The base line of the graph shows the charge per cent., and the ordinates give, for any charge, the rate of heat transmission in B.T.U. per square foot of lining surface area per minute

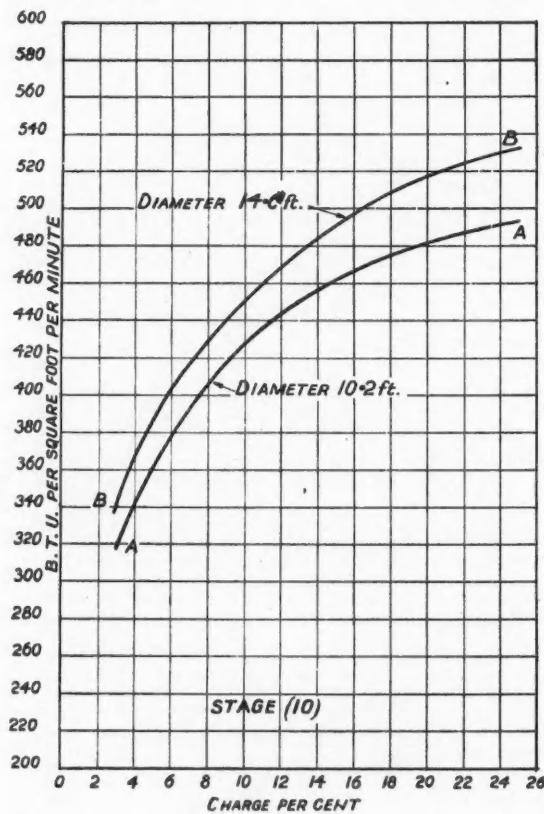


Fig. 33.

for stage (10), the diameter being 10.2 ft. Stage (10) is that in which the first half of  $\text{CaCO}_3$  is decomposed.

It should be mentioned that since a constant gas velocity is assumed in all cases the hourly coal consumption and the clinker output will be proportional to the areas given in line 2 of Table XXVIII. Hence if two kilns having charges

of 6 per cent. and 25 per cent. but with the same output are compared, the latter will be somewhat larger in diameter but considerably shorter since it would have a much greater rate of heat transmission per square foot of surface area. These remarks are made in connection with stage (10) and they are true for all stages where the material is dry on the surface. In stages (1) and (2), however, the heat transmission per square foot of surface only increases slightly as the charge is increased.

#### Diameter 14.6 feet—Charge Variable.

(190) A further series of calculations was made for a kiln diameter of 14.6 ft. The preliminary data for calculation purposes is given in Table XXIX and in para. (182) as before. The gas velocity is again taken at 26.6 ft. per second for all charges, so that the  $H_c$  values are nearly the same as for the kiln diameter of 10.2 ft., but the  $P.D.$  values in lines 7 and 8 and the values of  $F$  in line 9 are now considerably increased.

TABLE XXIX.

Preliminary data for stage (10).  
Charge variable—diameter 14.6 feet.

1	CHARGE IN KILN PER CENT.	3	5	10	15	20	25
2	Area of cross section, less charge sq. ft.	162.4	159.1	150.7	142.3	133.9	125.6
3	Equivalent diameter of kiln ft.	14.38	14.23	13.85	13.45	13.05	12.65
4	Gas velocity ft. per second	26.6	26.6	26.6	26.6	26.6	26.6
5	Convection	1.25	1.25	1.25	1.26	1.26	1.26
6	Constants $H_c$	Gas and lining	1.38	1.38	1.38	1.38	1.38
7	Values } for material		0.92	0.91	0.89	0.86	0.84
8	of $P.D.$	For $H_2O$	3.27	3.24	3.15	3.06	2.97
9	for $CO_2$		0.79	0.79	0.78	0.77	0.76
10	Density factor for coke particles, $F$	0.79	0.79	0.78	0.77	0.76	0.75
	Storage factor for kiln lining	0.73	0.74	0.74	0.73	0.72	0.71

(191) Calculations were made for each of the charges listed in Table XXIX using a kiln diameter of 14.6 ft. The rate of heat transmission per square foot of lining surface area per minute was obtained for each charge, and the result is shown by line BB on Fig. 33. The larger diameter is seen to give an improved rate of heat transmission, but an increase in the percentage charge is more effective.

#### Kiln with Extra Large Zones.

(192) Consideration can now be given to a kiln which is provided with zones exceptionally large in diameter for decomposing the  $CaCO_3$ , and for drying the slurry. This kiln, here referred to as the E.L.Z. (extra large zone) kiln, is shown to an enlarged vertical scale in Fig. 34. It is approximately 9.2 ft. in diameter inside the lining and 161 ft. long. There is an enlarged zone of 14.6 ft. in diameter inside the lining (marked D) in which the  $CaCO_3$  is decomposed, and another zone of the same diameter (marked B) in which the slurry is mainly dried. About 42 per cent. of the length of the kiln is provided with chains, which are hung from one end only.

The makers give the kiln output as 320 tons in 24 hours (or 500 lb. per minute) with a standard coal consumption of  $21\frac{1}{2}$  per cent. for slurry containing 40 per cent. of water. This clinker output is used for calculation purposes, but since this enquiry deals only with the effect of variations in the kiln diameter and in the charge per cent. the working conditions as regards percentage coal consumption, flame temperature, and the average gas composition and temperature in each stage are again assumed to be similar to those of the 400-ft. kiln. The kiln illustrated has a slope of 1 in 20, and makes on the average one revolution per minute.

**MOVEMENT OF THE CHARGE PER REVOLUTION AS DEDUCED FROM EXPERIMENTS ON MODELS.**—(193) It is necessary to know the charge per cent. in any position along the decomposition zone of the E.L.Z. kiln before the rate of heat transmission to it can be calculated, hence reference is now made to various small-scale experiments which have a bearing on the subject. The relation which exists between kiln diameter, rate of feed per revolution, and charge per cent., has been investigated by the writer, and particulars were given in this journal in January 1932.

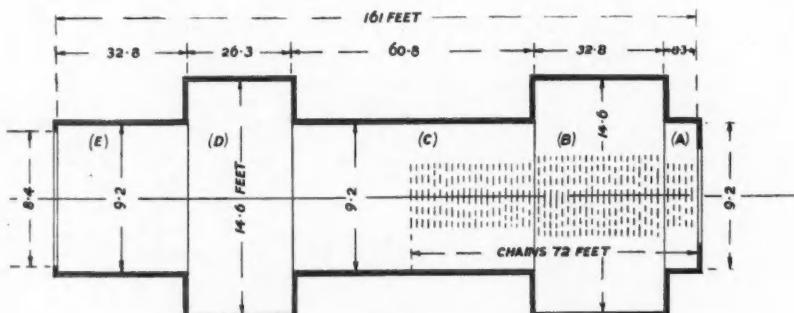


Fig. 34.

Experiments were made on cardboard tubes 2 in.,  $2\frac{1}{2}$  in., and 3 in. in diameter and 30 in. long. The material used was standard sand, and charges up to 9 per cent. were tried. The slope of the tube was 1 in 25 in all cases. With a steady rate of feed it was found that the movement of the material along the tube was independent of the charge volume and equal to 23.3 per cent. of the tube diameter per revolution. The relation between the volume of the feed per revolution, the diameter of the tube, and the charge per cent. was shown by a graph.

(194) Since these experiments were made the writer discovered that an exhaustive paper by Sullivan, Maier, and Ralston on the same subject was published by the U.S. Bureau of Mines in 1927 (Technical Paper 384). Five model tubes were used, the diameters ranged from 3 in. to  $19\frac{1}{2}$  in., and the length from 5 to 7 ft. The tubes were of iron, and the interior surfaces were roughened by sizing with glue or varnish and coating with sand. A large number of experiments were made at kiln slopes of 1, 2, 3, 4, 5 and 6 degrees and at various rates of feed,

the material used being mainly Ottawa standard sand. It was found (as one result) that the rate of advance of the charge per revolution was directly proportional to the slope. Charges up to 20 per cent. were used. For plain tubes, without end constrictions, the formula provided to represent the result of the experiments reduces to

$$M.p.d. = 9.63 a \dots \dots \quad (6)$$

where M.p.d. = movement of charge along tube per revolution per cent. diameter and  $a$  = slope of tube in degrees.

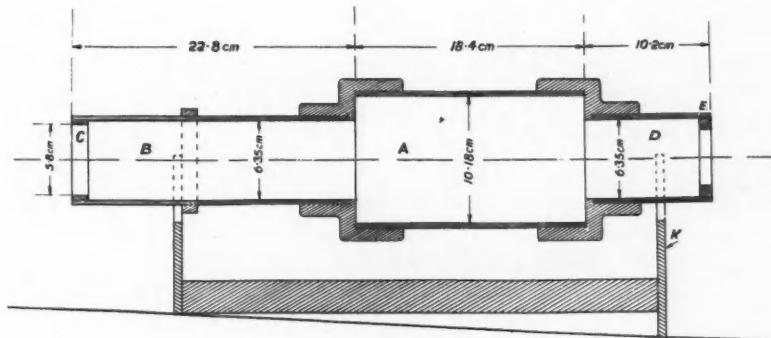


Fig. 35.

Similarly the experiments made by the writer on plain cardboard tubes at a slope of 1 in 25 using standard sand would be represented by

$$M.p.d. = 10.1 a \dots \dots \quad (7)$$

(195) The rate of advance of the charge per revolution per cent. diameter for a series of slopes likely to be used in practice, as derived from formula (6), is shown in Table XXX.

TABLE XXX.

Slope of tube.	Corresponding angle in degrees.	Movement of charge per revolution per cent. diameter. (M.p.d.)
1 in 25	2.30	22.1
1 in 24	2.38	23.0
1 in 23	2.49	24.0
1 in 22	2.60	25.0
1 in 21	2.73	26.2
1 in 20	2.87	27.6

The U.S. Bureau of Mines experiments dealt mainly with the time of passage of the material through the tubes. In some experiments constricting rings were used, both at the delivery end and in intermediate positions, and the time of passage in each case was expressed by a variation of formula (6).

MODEL OF EXTRA LARGE DECOMPOSITION ZONE.—(106) Since small scale experiments are a useful guide the writer made a model of the enlarged zone *D* and the delivery tube *E* in order to obtain further information as to the distribution of the charge in each portion under normal conditions of slope and speed. The model, see Figs. 35 and 36, was made of cardboard tubes joined together by turned hardwood rings. The relevant dimensions of the kiln are reproduced to scale. The interior of each tube was lined with smooth emery cloth. The decomposition zone *A* was 10.18 cm. in diameter by 18.4 cm. long, and the clinkering and delivery tube *B* was 6.35 cm. diameter by 22.8 cm. long. At the outlet *C* a hardwood ring 5.8 cm. in diameter was glued in. A short tube *D* was used to insert the feed. The outer circumference of the feed tube at *E* was divided into degrees, a paper scale being pasted on.

To determine the charge volume at any cross section of the tubes *A* or *B* a spike *F* was inserted (Fig. 36) and the angle turned through to bring the spike from the bottom of the charge at *G* to the top of the charge at *H* was noted on the scale by a pointer fixed to the end frame *K*.

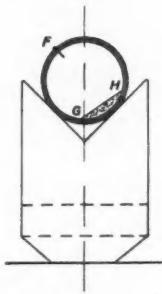


Fig. 36.

(197) The model was set up with a tube slope of 1 in 21.1 (or 2.71 degrees) and turned slowly by hand. For each three revolutions a feed of 10.8 c.c. of standard sand was inserted. As soon as the rate of discharge was equal to the rate of feed measurements were made of the angle subtended by the charge at a number of cross sections, and the charge per cent. at each cross section was subsequently calculated. The average result of two experiments is shown in Fig. 37. It will be seen that the charge in the enlarged zone varied from 13.9 per cent. at the feed end to 23.4 per cent. at the delivery end. The charge in the delivery tube *B* was 8.6 per cent. at the junction with the enlarged zone and 5.6 per cent. at the outlet, the average value being 7.5 per cent.

(198) The rate of delivery from the model is governed by the movement of the charge per revolution in the delivery tube, which is in accordance with formula (7). The advance of the material in the enlarged zone per revolution tends to be much greater owing to the larger diameter, hence it becomes piled up against the lower end of the zone as shown on the graph. For calculation purposes

the decomposition zone of the E.L.Z. kiln is assumed to carry an average charge of 18.6 per cent.

**HEAT TRANSMISSION IN EXTRA LARGE DECOMPOSITION ZONE.**—(199) In order to bring out the effect of the extra large zone as shown in Fig. 34 a calculation is first made of the length which would be required to decompose the  $\text{CaCO}_3$  in a normal kiln the diameter of which is 9.2 ft. and the charge 6 per cent. (It will be seen from Fig. 34 that the diameter of the E.L.Z. kiln on each side of the enlarged zone is 9.2 ft.). A second calculation is made of the length required to decompose the  $\text{CaCO}_3$  in the E.L.Z. kiln, the zone diameter being 14.6 ft. and the average charge 18.6 per cent. The clinker output in each case is 500 lb. per minute as given in para. (192). Comparisons of surface area, time, and horse power are then made.

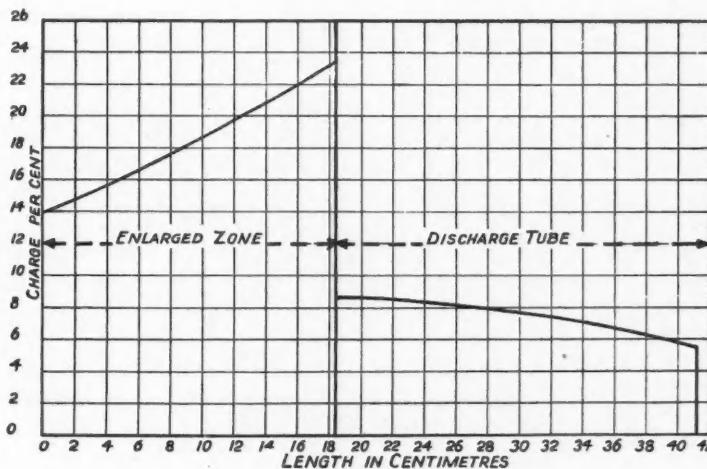


Fig. 37.

**(200) Case I. Normal kiln. Zone diameter 9.2 ft. Charge 6 per cent.**—From Fig. 32, and for a diameter of 9.2 ft., the heat transmission per square foot of surface per minute is seen from curve *BB* to be 371 B.T.U. To decompose one half of the  $\text{CaCO}_3$  the heat required is, from Table XXV, 4.42 lb. of standard coal per 100 lb. of clinker, hence the surface area required for heat transmission is

$$\frac{5.00 \times 4.42 \times 12,600}{371} = 751 \text{ sq. ft.}$$

The surface area inside the lining per foot run is  $9.2 \pi$ , or 28.9 sq. ft., hence the length required for Stage (10) is

$$\frac{751}{28.9} = 26.0 \text{ ft.}$$

It will be seen from Table XXV, line 25, that the total length of the decom-

position zone for the 400-ft. kiln is  $\frac{26.5 + 27.9}{26.5}$  or 2.05 times the length of Stage (10); hence in this instance the total length required for the decomposition zone is approximately  $2.05 \times 26.0 = 53.3$  ft.

(201) *Case II. E.L.Z. kiln. Zone diameter 14.6 ft. Average charge 18.6 per cent.*—From curve BB on Fig. 33 the rate of heat transmission is seen to be 512 B.T.U. per square foot per minute, hence the surface area required for Stage (10) will be

$$\frac{5.00 \times 4.42 \times 12,600}{512} = 544 \text{ sq. ft.}$$

The surface area inside the lining per foot run is  $14.6\pi$ , or 45.87 sq. ft., hence the length required is

$$\frac{544}{45.87} = 11.85 \text{ ft.}$$

The total length required for the decomposition zone, as previously explained, will be

$$2.05 \times 11.85 = 24.3 \text{ ft.}$$

\*The length shown on Fig. 34 is 26.3 ft., hence the enlarged zone would apparently be able to do something more than decompose the  $\text{CaCO}_3$ .

The high rate of heat transmission per square foot of surface in the extra large zone is seen from Fig. 33 to be mainly due to the volume of the charge.

POWER REQUIRED.—(202) An approximate estimate may be made of the power required to turn the decomposition zone in each case. The partly decomposed material is assumed to weigh on the average 75 lb. per cubic foot as packed in the kiln, and the frictional loss in the supporting and driving mechanism is taken at 12 per cent. of the power transmitted.

(203) *Normal kiln. Zone diameter 9.2 ft. Charge 6 per cent.*—Since the length of the decomposition zone is 53.3 ft. the total weight of the charge becomes

$$\frac{66.5 \times 6 \times 53.3 \times 75}{100} = 15,950 \text{ lb.}$$

The radius to the centre of gravity of the charge is 3.98 ft., hence the actual work done per revolution, or per minute, is  $15,950 \times 3.98 \times 2\pi$  ft. lb., and the B.H.P. required at 88 per cent. efficiency is

$$\frac{15,950 \times 3.98 \times 2\pi}{33,000 \times 0.88} = 13.7$$

(204) *E.L.Z. kiln. Zone diameter 14.6 ft. Charge 18.6 per cent.*—The length of the decomposition zone as calculated is 24.3 ft., hence the weight of the charge becomes

$$\frac{167.5 \times 18.6 \times 24.3 \times 75}{100} = 56,780 \text{ lb.}$$

The radius to the centre of gravity of the charge is 5.21 ft., hence the B.H.P. required (since the kiln makes one revolution per minute) is

$$\frac{56,780 \times 5.21 \times 2\pi}{33,000 \times 0.88} = 64.0$$

TIME REQUIRED FOR DECOMPOSITION.—(205) It may be of interest to determine the length of time the  $\text{CaCO}_3$  is under decomposition in each case. The dry raw material entering the zone is 758 lb. per minute, and the material leaving the zone and about to be clinkered is 500 lb. per minute. If we assume the average value of 629 lb. per minute, the length of time the material is in the decomposition zone of the normal kiln which contains 15,950 lb. of material is  $\frac{15,950}{629} = 25.4$  minutes. Similarly the length of time the material will remain in the decomposition zone of the E.L.Z. kiln which contains 56,780 lb. of material is

$$\frac{56,780}{629} = 90.3 \text{ minutes.}$$

#### SUMMARY

(206) At a clinker output of 500 lb. per minute in a kiln 9.2 ft. in diameter, not provided with an enlarged zone, the time of decomposition of the  $\text{CaCO}_3$  is 25.4 minutes, and the B.H.P. required to turn that part of the kiln is estimated at 13.7.

If an extra large zone 14.6 ft. in diameter is provided the time of decomposition is increased to 90.3 minutes and the B.H.P. required to turn that part of the kiln is estimated to be 64.0.

The surface area of the charge in the decomposition zone is found on calculation to be approximately the same in both kilns, hence the length of time that any given lump is exposed to the action of the flame, or to radiation from the lower arc of the kiln lining, should also be nearly the same. In the E.L.Z. kiln, however, a lump would remain buried for a much longer period, and probably with real advantage in the case of the larger lumps.

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#### Recent Patent Applications.

409,120.—G. O. Case and Carbo-Lime and Cement Co., Ltd.: Production of hydraulic cement.

409,139.—N. Kyriacou: Furnaces for the heat treatment of cement and other materials.

409,147.—J. Wilson and D. G. Gow: Composition for waterproofing cement or plaster materials.

409,166.—Soc. Anon. Des Ciments Francais et des Portland de Boulogne-Sur-Mer et Compagnie Des Portland De Desvres: Manufacture of cement.

409,511.—C. J. Choremie: Manufacture of cement or like hydraulic binders.

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#### Lepol Kiln in Japan.

At the recent annual meeting of the Japanese Portland Cement Society it was reported that an output of 150 tons of clinker per day and a heat consumption of 100,000 kg. cal. per 100 kg. clinker had been guaranteed for the new Lepol Kiln (Polysius-Lellep process) installed by the Mikwa Cement Co., and that in the acceptance test an output of 172 tons of clinker per day and a heat consumption of 86,500 kg. cal. per 100 kg. clinker was obtained.

## Heat of Hydration of Cement and its Constituents.—II.

By O. F. HONUS

### Calculation of the Heats of Hydration of the Compounds of the Ternary System $\text{CaO}-\text{Al}_2\text{O}_3-\text{SiO}_2$ .

IN Part I the heats of solution were calculated by means of thermo-chemical equations for all the oxides involved in the constitution of cement, and for the hydrates of these oxides. It is now proposed to determine the heats of solution of the calcium silicates, the calcium aluminates, calcium ferrite and magnesium silicate and their hydrates, and, from the differences, the heats of hydration. The heats of solution of the compounds are obtained by subtracting the heat of formation of the compound from the oxides from the sum of the heats of solution of the oxides.

#### (1) Heat of Hydration of $\text{CaO} \cdot \text{SiO}_2$

- (a) Heat of solution of  $\text{CaO}$  (equation 3) = +46.9 kcal.
- Heat of solution of  $\text{SiO}_2$  (equation 25) = +29.9 kcal.
- Heat of solution of  $\text{CaO} + \text{SiO}_2$  = +76.8 kcal.
- Heat of formation of  $\text{CaO} + \text{SiO}_2$  = +19.6 kcal.<sup>136</sup>
- Heat of solution of the compound  $\text{CaO} \cdot \text{SiO}_2$  . . . . . 57.2 kcal.
- (b) Heat of solution of  $\text{Ca}(\text{OH})_2$  (equation 6) = + 32.0 kcal.
- Heat of solution of  $\text{SiO}(\text{OH})_2$  (equation 26) = + 25.7 kcal.
- Heat of solution of the hydrates  $\text{Ca}(\text{OH})_2 + \text{SiO}(\text{OH})_2$  57.7 kcal.
- Heat of hydration of  $\text{CaO} \cdot \text{SiO}_2$  = . . . . . - 0.5 kcal.

#### (2) Heat of Hydration of $\beta 2\text{CaO} \cdot \text{SiO}_2$

- (c) Heat of solution of  $2\text{CaO}$  (equation 3) = +93.8 kcal.
- Heat of solution of  $\text{SiO}_2$  (equation 25) = + 29.9 kcal.
- Heat of solution of  $2\text{CaO} + \text{SiO}_2$  = + 123.7 kcal.
- Heat of formation of  $2\text{CaO} + \text{SiO}_2$  = + 28.3 kcal.<sup>137</sup>
- Heat of solution of the compound  $\beta-2\text{CaO} \cdot \text{SiO}_2$  = 95.4 kcal.
- (d) Heat of solution of  $2\text{Ca}(\text{OH})_2$  (equation 6) = +64.0 kcal.
- Heat of solution of  $\text{SiO}(\text{OH})_2$  (equation 26) = + 25.7 kcal.
- Heat of solution of the hydrates  $2\text{Ca}(\text{OH})_2 + \text{SiO}(\text{OH})_2$  = 89.7 kcal.
- Heat of hydration of  $\beta-2\text{CaO} \cdot \text{SiO}_2$  = . . . . . + 5.7 kcal.

#### (3) Heat of Hydration of $\gamma-2\text{CaO} \cdot \text{SiO}_2$

- (e) Heat of solution of  $2\text{CaO} + \text{SiO}_2$  (2C. above) = + 123.7 kcal.
- Heat of formation of  $\gamma-2\text{CaO} \cdot \text{SiO}_2$  (Nacken<sup>138</sup>) = 36.1 kcal.
- Heat of solution of the compound  $\gamma-2\text{CaO} \cdot \text{SiO}_2$  = . . . . . 87.6 kcal.
- (f) Heat of solution of the hydrates  $2\text{Ca}(\text{OH})_2 + \text{SiO}(\text{OH})_2$
- (2d above) = . . . . . . . . . . . 89.7 kcal.
- Heat of hydration of  $\gamma-2\text{CaO} \cdot \text{SiO}_2$  = . . . . . - 2.1 kcal.

(4) Heat of Hydration of  $3\text{CaO} \cdot \text{SiO}_2$ 

(g) Heat of solution of  $3\text{CaO}$  (equation 3) =  $3 \times 46.9 = + 140.7$  kcal.  
 Heat of solution of  $\text{SiO}_2$  (equation 25) = .. + 29.9 kcal.  
 Heat of solution of  $3\text{CaO} + \text{SiO}_2$  = .. + 170.6 kcal.  
 Heat of formation from the oxides  $3\text{CaO} + \text{SiO}_2$   
 (Tschernobaeff<sup>139</sup>) = .. .. .. 28.6 kcal.  
 Heat of solution of the compound  $3\text{CaO} \cdot \text{SiO}_2$  = .. 142.0 kcal.

(h) Heat of solution of  $3\text{Ca}(\text{OH})_2$  (equation 6) = .. + 96.0 kcal.  
 Heat of solution of  $\text{SiO}(\text{OH})_2$  (equation 26) = .. + 25.7 kcal.  
 Heat of solution of the hydrates  $3\text{Ca}(\text{OH})_2 + \text{SiO}(\text{OH})_2 = 121.7$  kcal.  
 Heat of hydration of  $3\text{CaO} \cdot \text{SiO}_2$  = .. .. .. 20.3 kcal.

(5) Heat of Hydration of  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ 

(i) Heat of solution of  $3\text{CaO}$  = .. + 140.7 kcal.  
 Heat of solution of  $\text{Al}_2\text{O}_3$  (equation 38) = .. + 78.9 kcal.  
 Heat of solution of  $3\text{CaO} + \text{Al}_2\text{O}_3$  = .. + 219.6 kcal.  
 Heat of formation of  $3\text{CaO} + \text{Al}_2\text{O}_3$  (Thorvaldson<sup>140</sup>) = 20.7 kcal.  
 Heat of solution of the compound  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$  = .. 198.9 kcal.

(j) Heat of solution of  $3\text{Ca}(\text{OH})_2$  = .. .. .. + 96.0 kcal.  
 Heat of solution of  $\text{Al}_2(\text{OH})_6$  (equation 41) = .. + 48.1 kcal.  
 Heat of solution of the hydrates  $3\text{Ca}(\text{OH})_2 + \text{Al}_2(\text{OH})_6 = 144.1$  kcal.  
 Heat of hydration of  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$  = .. .. .. + 54.8 kcal.

The investigations of Thorvaldson and his colleagues yielded a value of 57.7 kcal., so the calculated value of 54.8 kcal. for the heat of hydration of  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$  constitutes a good approximation for use in practice.

The heats of hydration of the main constituents of Portland cement— $\beta\text{-}2\text{CaO} \cdot \text{SiO}_2$ ,  $\gamma\text{-}2\text{CaO} \cdot \text{SiO}_2$ ,  $3\text{CaO} \cdot \text{SiO}_2$  and  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ —have thus been calculated, but the heats of hydration are still required for  $2\text{MgO} \cdot \text{SiO}_2$  and  $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$ . These can now be calculated as preliminary experiments have given the following values for the heats of formation of these compounds:

$2\text{MgO} \cdot \text{SiO}_2$ , 16.0 kcal.;  $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$ , 23.3 kcal.

(6) Heat of Hydration of  $2\text{MgO} \cdot \text{SiO}_2$ 

(k) Heat of solution of  $2\text{MgO}$  (equation 22) =  $2 \times 33.9 = 67.8$  kcal.  
 Heat of solution of  $\text{SiO}_2$  (equation 25) = .. .. 29.9 kcal.  
 Heat of solution of  $2\text{MgO} + \text{SiO}_2$  = .. .. .. 97.7 kcal.  
 Heat of formation of  $2\text{MgO} + \text{SiO}_2$  = .. .. .. 16.0 kcal.  
 Heat of solution of  $2\text{MgO} \cdot \text{SiO}_2$  = .. .. .. 81.7 kcal.

(l) Heat of solution of the hydrates  $2\text{Mg}(\text{OH})_2 + \text{SiO}(\text{OH})_2$  (equations 23 and 26) = .. .. .. 82.7 kcal.  
 Heat of hydration of  $2\text{MgO} \cdot \text{SiO}_2$  = .. .. .. - 1.0 kcal.

(7) Heat of Hydration of  $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$ 

(m) Heat of solution of  $2\text{CaO} + \text{Fe}_2\text{O}_3$  (equations 3 and 42) = 124.7 kcal.  
 Heat of formation of  $2\text{CaO} + \text{Fe}_2\text{O}_3$  = .. .. 23.3 kcal.  
 Heat of solution of the compound  $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$  = .. 101.4 kcal.

(n) Heat of solution of the hydrates  $2\text{Ca}(\text{OH})_2 + \text{Fe}_2(\text{OH})_6$

(equations 6 and 43) = .. .. .. .. 99.4 kcal.

Heat of hydration of  $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$  = .. .. + 2.0 kcal.

It should be noted that, owing to the partial dissociation of the ferric oxide



there is some difficulty in preparing pure dicalcium ferrite and a consequent lowering of the positive heat of formation. The significance of the dissociation of the ferric oxide in cement burning has been discussed recently by Kühl and Rasch.<sup>141</sup> The degree of dissociation can easily be calculated for pure ferric oxide, monocalcium ferrite, dicalcium ferrite, Brownmiller's compound and Portland cement from the values found by these investigators; the values are, respectively, 82.8, 23.2, 17.2, 12.0 and 11.2 per cent.

A summary of the heats of hydration that have been calculated in the present paper is given in Table II.

TABLE II.—HEATS OF HYDRATION.

Compound.	Approx. mol. weight.	Heat of hydration. Kcal/mol.	Cal/g.
$\text{CaSiO}_3$ .....	116	- 0.5	- 4
$\beta\text{-Ca}_2\text{SiO}_4$ .....	172	+ 5.7	+ 33
$\gamma\text{-Ca}_2\text{SiO}_4$ .....	172	- 2.1	- 12
$\text{Ca}_3\text{SiO}_5$ .....	228	+ 20.3	+ 89
$\text{Ca}_3\text{Al}_2\text{O}_6$ .....	270	+ 54.8	+ 203
$\text{Ca}_3\text{Fe}_2\text{O}_6$ .....	272	+ 2.0	+ 7
$\text{Mg}_2\text{SiO}_4$ .....	140	- 1.0	- 7
$\text{CaO}$ .....	56	+ 14.9	+ 226

#### REFERENCES.

<sup>138</sup> W. A. Roth and P. Chall, *Zeitschr. f. Elektrochem.*, 1929, **34**, 198.  
<sup>137</sup> T. Tschernobaeff, *Electrochemical and Metallurgical Industry*, 1906, **4**, 72.  
<sup>138</sup> R. Nacken, *Zement*, 1930, **19** (35), 818-24.  
<sup>139</sup> T. Tschernobaeff, *Revue de Metallurgie*, 1905, **2**, 729.  
<sup>140</sup> T. Thorvaldson, W. G. Brown and C. R. Peaker, *J. Am. Chem. Soc.*, 1930, **52**, 3926.  
<sup>141</sup> H. Kühl and R. Rasch, *Zement*, 1931, **20** (36), 812-6; (37), 833-6.

#### Recent Patent.

##### Mortars, Concretes, and Plasters.

402,422.—Rodwell, A. G., 22, Parkholme Road, Dalston, London. May 18, 1932.

Waterproofing compositions for cement, plaster, and concrete are made by mixing gelatinous silica with diluted rubber latex and adding a solution of alkali silicate. Fireproofing agents such as alum, borax, and aluminium sulphate may be added to the diluted latex. The solution may be used in mixing cement, concrete, and plaster, in which case the addition of aluminium sulphate accelerates the setting of the cement.

#### PATENT.

THE PROPRIETORS of British Patents No. 275,463 for "Improvements in or relating to the treatment of Carbonate Materials," and No. 269,480 for "Improvements in or relating to methods of and apparatus for treating materials," desire to introduce their inventions to the notice of manufacturers and others with a view to the inventions being worked commercially under licence or otherwise. All communications to be addressed to JENSEN & SON, Chartered Patent Agents, 77, Chancery Lane, London, W.C.2

## Some Properties of Cement and Concrete.

THE following is an extract from a paper recently read to the Society of Swedish Engineers in Great Britain, by Messrs. D. Werner and S. Giertz-Hedström.

About five years ago the Cement Laboratory at the Royal Swedish Institute for Engineering Research began a systematic investigation of cements generally, and, in particular, the possibilities of useful differentiation in the manufactured product were exhaustively studied. So many different demands are made for the improvement of cement that it seems impossible to satisfy even those that are eminently reasonable and desirable simultaneously with one and the same kind of cement. For example, if a Portland cement is modified so that it generates the minimum amount of heat with a slow rate of temperature rise, in order that it may be particularly suitable for concrete construction in large masses, the hardening process will be considerably retarded, and the cement will be unsuitable where a rapid increase in strength is desired. In order to determine the principles on which specialisation of cement characteristics should proceed it is, therefore, necessary to set out clearly which properties are essential in different cases, how they shall be measured, and their relations. The question then arises how the changes in cement can be secured in practice, and whether on economic grounds any of the practical solutions are justified. The requirements of economic production clearly restrict the choice to a limited number of types.

### Strength Tests.

The usual methods of determining the strength of cement by tests on cement mortar or neat cement do not give results in strict relation to the conditions met with in concrete. This divergence is most marked when the tests are made with the object of comparing different kinds of cement. An improvement in the procedure of testing is desirable, particularly as increased specialisation in the manufacture of cement will result in wider variation of physical and chemical characteristics than has hitherto been usual.

The authors have applied simultaneously the methods of strength determination indicated by three distinct methods, viz. : (a) the present Swedish Standard Specification ; (b) the new Swiss Standard Specification ; and (c) a method proposed by Dr. G. Haegermann. The Swedish specification prescribes for the preparation of test specimens a low water content (water-cement-ratio about 0.33), standard sand of uniform grain size, and machine tamping (Böhme-Martens hammer apparatus). Compression tests are made on 1 : 3 cubes with 50-sq. cm. faces, and tension tests on 1 : 3 eight-shape briquettes of similar dimensions to British Standard briquettes. The Swiss specification prescribes a relatively high water content (water-cement-ratio 0.44), uniform normal sand and hand tamping, and bending tests (for the calculation of the transverse-tensile strength) made on 1 : 3 prisms, 4 cm. by 4 cm. by 16 cm., on knife-edge supports. For the compression tests the prism pieces resulting from the bending tests are utilised. Haegermann's method of testing is similar to the Swiss, but the former prescribes

a larger water content (water-cement-ratio 0.64) and the use of a mixture of the usual uniform grain standard sand and finely ground special sand.

The general trend of the strength curves obtained by the three methods of testing is shown in Figs. 1 and 2 for an ordinary Portland cement. Tests in accordance with the Swedish specification show considerably higher values for the compressive strength at less age, but as the age increases the increase in strength is considerably less than it is in the case of tests by the two other methods. The chief reason for this is the difference in water content. The tensile strengths obtained by the Swiss and Haegermann's methods are considerably higher than those obtained by the Swedish specification. The dependence of tensile strength on the water content is far more striking than in the case of compressive strength. The differences between various cements appear more clearly when the tests are made according to the Swiss specification and according to Haegermann's method than when the Swedish specification is used, and this is especially true as regards tensile strength.

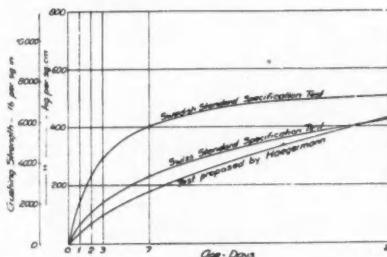


Fig. 1.

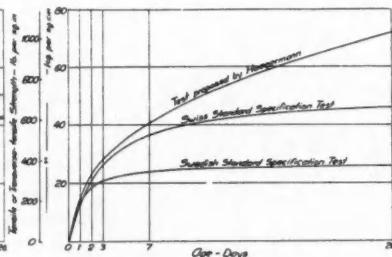


Fig. 2.

In spite of the difficulties in the preparation of the special sand mixture required by Haegermann's method, that method is decidedly to be preferred to the others. The water content is in closer agreement with works practice, and the introduction of fine sand renders possible a juster appreciation of the different cements. The determination of the transverse tensile strength according to the Swiss and Haegermann's methods is considerably more exact and satisfactory than in the Swedish method.

The chief reason why it is desirable to employ a large water content for cement mortar tests is that the strength values then obtained correspond more closely with those of the final concrete. From English tests of five kinds of cement it appears that the values of the compressive strength of 1:3 cement mortar with a water-cement-ratio of 0.58 are the same as the compressive strength of 1:2:4 concrete with a water-cement-ratio of 0.60. Conclusions as to the strength of concrete, drawn from the values for the strength of mortar with a water-cement-ratio of 0.32, are indefinite.

#### Strength Relations.

A question often asked is how the relation between tensile strength and compressive strength may be improved so that the tendency to crack may be de-

creased and a tougher concrete obtained. It has been pointed out that high-strength cements show a low tensile strength in comparison with the compressive strength, and that, if possible, this should be changed. A great number of tests, comprising about 1,500 test specimens, have been carried out at Stockholm on twelve different kinds of cement employing the three methods of testing already described. The tests covered both crushing strength, and tensile (transverse-tensile) strength, the results being shown in Figs. 3, 4 and 5. R. Feret was probably the first to indicate that the tensile strength is approximately proportional to the  $2/3$  power of the compressive strength and curves representing this relation with suitably selected proportionality factors have been inserted in the diagrams. The diagrams show that test values agree with this relation less satisfactorily in tests made to the Swedish specification, better in tests according to the Swiss specification, and remarkably well in tests according to the

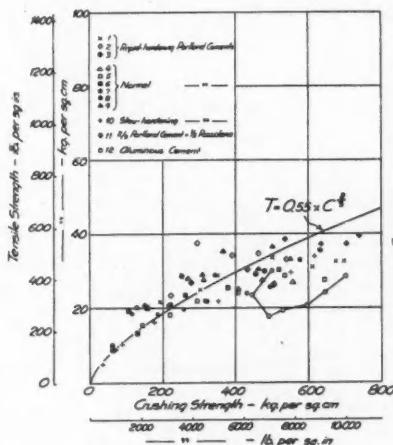


Fig. 3.

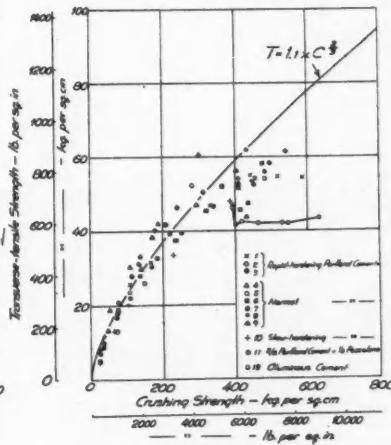


Fig. 4.

Haegermann method. The agreement holds good, in spite of great variations in the composition of the cements, so that it appears to be fundamental in the case of Portland cement. For aluminous cement, for which the test values are marked in the diagrams with rings, the relation does not apply.

Accordingly the relation between the tensile strength and the compressive strength is fixed, and an attempt to improve it by changing the composition of the cement would lead to no result, at least within the limits of what may be called Portland cement. High strength is accompanied by a comparatively low relation between the tensile strength and the compressive strength, and a high ratio can only be obtained from cement of moderate strength.

It is superfluous to measure both the compressive strength and the tensile strength, as the one can be calculated from the other. The strength to be measured should be the one which is the simplest to determine, and which can

be obtained with the greater accuracy—that is, the transverse-tensile strength. When estimating the strength value of a cement it should therefore be sufficient in ordinary cases to determine the transverse-tensile strength (for instance, by Haegermann's method) from which the compressive strength of the cement and the compressive strength of the corresponding type of concrete could then be calculated. It is suggested that the combined method of storage prescribed by some standard specifications, the value of which is debatable, should be abandoned, and that storage of the briquettes should only take place in water. The strength characteristics of the cement could then be limited to one strength figure only for each age, which, however, with a suitably selected testing method, would give a truer expression of the strength value than the two to four values which it has hitherto been usual to obtain in most countries.

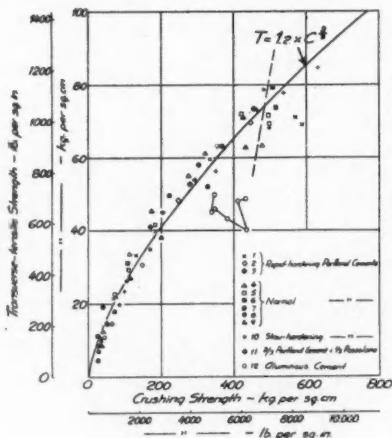


Fig. 5.

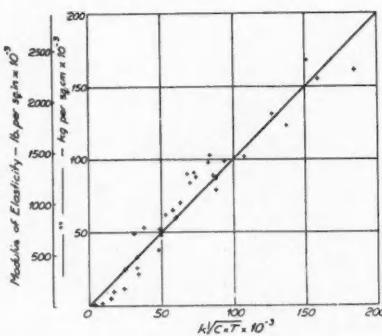


Fig. 6.

By a number of tests it has been possible to establish the following simple relation between the strength properties of neat cement.

where  $E$  = modulus of elasticity.

**C** = compressive strength of 50-sq. cm. cubes.

$T$  = tensile strength of eight-shape briquettes and

$k = \text{constant}$

The result (Fig. 6) applies to test specimens of an age between one and twenty-eight days. It is probable that this relation holds good also for cement mortar.

### Durability of Pipes.

The solubility of cement in pure water is reduced appreciably if the water is hard. Rain water and water from melted snow and ice, which have not taken up lime to any considerable extent, are therefore characterised by appreciable

aggressiveness, which may be greatly increased if the water takes up carbon dioxide, in which case its degree of acidity may become considerable (low  $pH$ ). In districts with a chalky soil the aggressiveness of the water is usually very quickly reduced as it takes up lime, and such water is therefore generally much more favourable to the durability of concrete, unless the carbon dioxide content is at the same time extremely high.

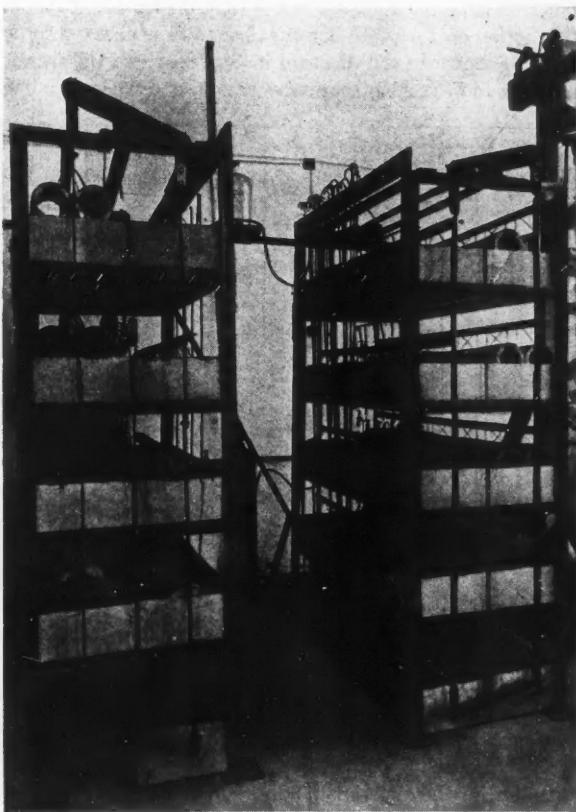


Fig. 7.

A series of experiments has been carried out mainly dealing with the durability of concrete pipes in natural Swedish surface waters. The results can, however, to a certain extent be applied to other cases where concrete is exposed to similar action. These surface waters are characterised chiefly by varying contents of carbon dioxide, humus, and calcium bicarbonate (temporary hardness). Owing to soil conditions in Sweden, the sulphate content is generally

very low, and the magnesia content, too, is of less importance, so that these can as a rule be neglected.

The experimental arrangements used in these investigations are shown in Fig. 7. Concrete pipes of 4 in. internal diameter, manufactured by various methods (hand tamping, machine tamping, machine pressing, and the centrifugal process) are being continuously dipped in waters of varying chemical composition. Each specimen is immersed at the rate of 2,000,000 times per annum, and, up to the present, the experiments have been going on for about eighteen months. The aggressive action on the pipes is from time to time checked by weighing.

The results are shown in the diagram in Fig. 8, where the waters have been arranged according to increasing aggressive action, and where the life of concrete

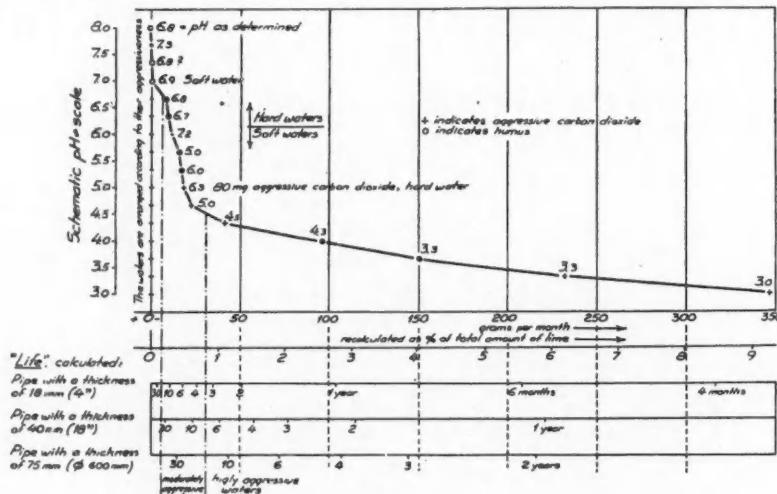


Fig. 8.

pipes of various thicknesses has been shown for the different waters, it being assumed that the concrete is worthless when one-third of its lime content has been dissolved. On the whole, the aggressive action of water increases with increasing degrees of acidity (decreasing  $\text{pH}$ ).

The humus used in the experiments does not seem to have had an aggressive effect, even when the humus content was high. This observation is in accord with those made elsewhere, for which reason it would seem justifiable to assume that a humus content in the water is not aggressive in itself. The fact that water containing humus is often poor in lime and comes from boggy and peaty districts, where it has obtained an appreciable content of carbon dioxide, results in its often being aggressive on that account. The degree of acidity ( $\text{pH}$ ) of the water does not give a simple measure of the aggressive action, but bears a relation to it only as an expression of its softness and content of aggressive carbon dioxide.

Fig. 9 shows the relation between the aggressive carbon dioxide, the temporary hardness, and the amount of free carbon dioxide. The dotted lines indicate the *pH* values (hydrogen-ion concentration of the waters).

From the results it was possible to make an approximate division of surface waters into classes for the estimation of their aggressive action, and this classification has been incorporated in a proposal for a Swedish specification for concrete pipes and culverts. The classification comprising four different kinds of water is shown in Table I.

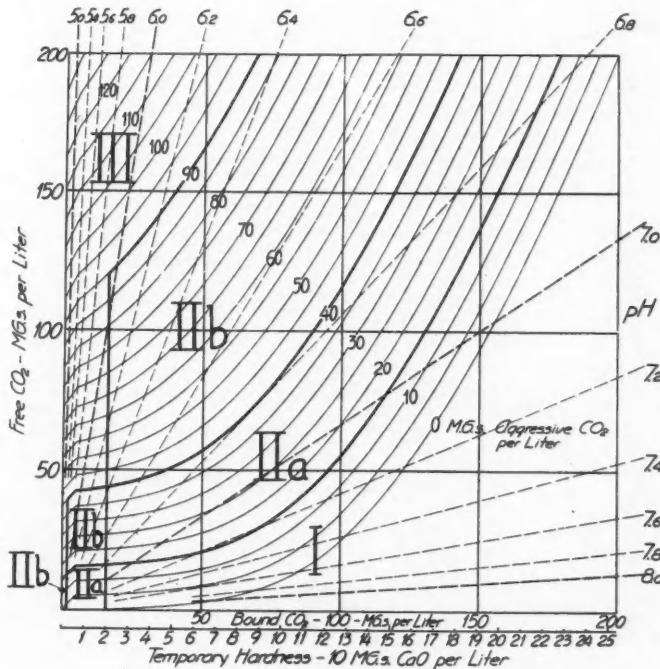


Fig. 9.

If the water is of type I or IIa it is considered unnecessary to take any special precautionary measures, assuming, of course, that the quality of the concrete is in accordance with the standard specification. If the water is of type IIb a surface treatment is recommended, especially when the water flow is large. Finally, with water of type III such surface treatment should unquestionably be prescribed. In the proposed specifications, it has, however, been assumed that a binding medium may be used which is considerably less soluble in water than ordinary Portland cement, and the directions for surface treatment therefore apply to concrete pipes of ordinary manufacture.

Experiments have also been made on concrete pipes made of aluminous cement. The durability of this concrete was fully in agreement with that of ordinary Portland cement concrete.

TABLE I.

Type of water.	Composition of the waters.		Aggressiveness of the water.
	Temporary hardness, 10 mg. CaO per litre.	Aggressive carbon dioxide, mg. per litre.	
I	Larger than 2.0	Less than 15	Practically none
IIa	Larger than 2.0 2.0-0.2	15-40 Less than 15	Slight
IIb	Larger than 2.0 2.0-0.2 Less than 0.2	40-90 15-40 Less than 15	Considerable
III	Larger than 2.0 2.0-0.2 Less than 0.2	Larger than 90 Larger than 40 Larger than 15	Great

In view of the fact that in certain cases coating is prescribed in the proposed specifications, a number of coating materials have been studied from the point of view of their protective properties against water and against mechanical erosion. It has been shown that none of the coating materials so far tested has been able entirely to prevent the penetration of water, and that the protective capacity of one and the same material has, practically without exception, been considerably less when the water contained carbon dioxide than when it had a humus content. Even though a surface treatment material is not absolutely impervious to water, it leads, however, to a certain retardation of the water penetration of the concrete.

Exhaustive tests of erosion have been carried out, coated concrete pipes being subjected to a standard mixture of gravel and water flowing through the pipes, the wear and tear being studied as a function of time.

By means of these tests it has been possible to make a classification of a number of surface treatment materials in use in Sweden, and it has proved that, of the cases examined, a surface treatment with asphalt dissolved in solvent naphtha or some other suitable solvent, with a subsequent coating of warm asphalt, gave decidedly the best protection against both penetration of water and mechanical wear and tear.

#### Water Fixation in Set Cement.

The fact that set cement consists, not only of more or less changed cement, but also to a large extent of water in various fixed or bound forms, makes it desirable to investigate the nature and amount of this water. If a crushed specimen of concrete or neat cement is dried in air of a certain humidity, the water content of the specimen is increased or decreased to a fixed value, determined by the value of the humidity of the air and the properties of the specimen.

Fig. 10 shows the changes in the water-content of such a specimen of Portland cement, when it is heated with air of 0 to 97 per cent. relative humidity. After three hours' exposure the amount of water retained by the cement is practically constant. Taking the values after a three hours' test as a measure of the water-holding capacity of the specimen, these values, set in relation to the relative humidity of the air, give the curve I shown in Fig. 10, which indicates a vapour pressure isotherm for the specimen in question. This isotherm affords a fairly complete indication of the character of the water fixation in the specimen and

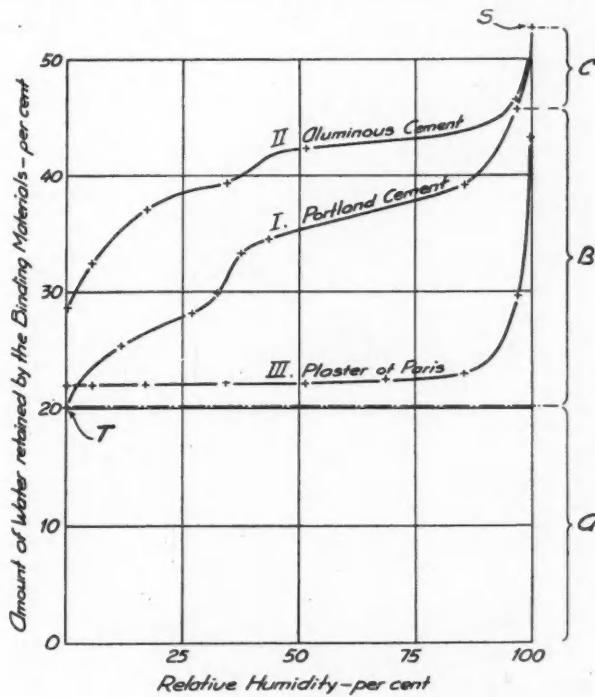


Fig. 10.

shows that for the sake of clearness it is appropriate to divide the water in the set cement into different classes. Owing to the method of measurement, and to the fact that the transition between the different classes is continuous, the division must to some extent be arbitrary. In Fig. 10 *a* indicates fixed water chemically combined in the hydration products and firmly adsorbed by the surface, *B* indicates half-fixed water retained by the gel material in the specimen, and *c* free water enclosed in the coarser pores of the material. If the original specimen had been fully water saturated the drying would have begun at *S* with

free water. It then follows the curve shown for Portland cement, the drying out of free water being continued by the drying out of half-fixed water until point T is reached. The drying out then ceases, fixed water only being left in the specimen.

A comparison between the water-binding curves which are obtained if corresponding drying experiments are carried out on plaster of Paris, aluminous cement, and Portland cement is shown in Fig. 10. That the half-fixed water has a definite connection with the gel material in the specimen is clearly illustrated by the results obtained with plaster of Paris, which is a gel-free material. Half-fixed water is almost entirely absent here, while both fixed and free water are present in considerable quantities.

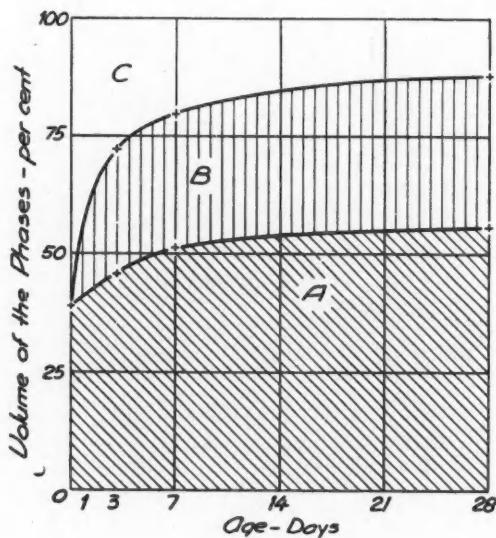


Fig. 11.

The progress of the reaction between cement and water is clearly reflected in the water fixation curves. In Fig. 11 the changes in volume of the different kinds of water in set Portland cement have been set off as functions of the age of the specimen, the volume of fixed water being added to the original volume of the cement. These two constitute the solid phase (A) in the hardening specimen of cement. The free water (C) can, in conformity with this, be regarded as the liquid phase, and the half-fixed water (B) as a half-solid phase. As water is dried out of the material it is replaced by a corresponding volume of air.

*Fixed Water.*—The different kinds of water play an important rôle in respect to the properties of the material. Thus it is clear that the fixed water bears a relation to the strength. This relation between the compressive strength and

the volume of the solid phase of different kinds of hardened cement can be expressed by the empirical formula :

$$C = k \cdot (S - 25)^2 \dots \dots \dots \dots \dots \dots \quad (2)$$

where  $C$  = compressive strength of 50-sq. cm. cubes,

$S$  = percentage by volume of solid phase,

$k$  = constant.

It has also been possible to set up formulæ for the relation between the percentage by volume of the solid phase and the tensile strength and the modulus of elasticity respectively. A combination of these relations gives formulæ of the same nature as (1).

*Half-fixed Water.*—There is also a relation between the percentage by volume of half-fixed water and the shrinking of the material as a result of drying, although it is probably of a more complex nature. The loss of the free water through drying does not lead to shrinkage. When the half-fixed water is lost, however, considerable capillary forces are set up which compress the material, and this is manifested outwardly as a shrinkage, and the more the specimen is dried the greater are the capillary forces. The following formula can be employed for the calculation of the maximum shrinkage that these forces are capable of causing :

$$\Sigma = \frac{P(1 - z/m)}{E} \dots \dots \dots \dots \dots \dots \quad (3)$$

where  $\Sigma$  = specific linear shrinkage,

$m$  = Poisson's ratio.

$E$  = modulus of elasticity (under compression),

$P$  = load resultant on drying.

This formula, however, gives shrinkage values which are larger than those determined by measurement, which is due to the fact that hardened cement does not consist of 100 per cent. gels. How correction is to be reached is not yet clear.

The same forces that caused a contraction in drying are also the cause of the increase in the mechanical strength observed in specimens of cement and concrete when dried.

*Free Water.*—In a water-saturated specimen the content of free water is a measure of the occurrence of coarser pores in the material. If the free water is defined as that which can be dried out of the specimen by means of air whose relative humidity is 97 per cent., this implies that the free water occurs in pores, the mean diameter of which exceeds about 0.00007 mm. Since the free water is thus a measure of coarse porosity of the material, the amount of this water determines the permeability of the material to water at low pressure—that is, its density in the usual sense of the word. The greater the pressure that is used to force the water through, however, the greater the influence of the relatively fine pores. Thus, if a pressure of the same order as the capillary forces is used, then even the extremely small pores holding half-fixed water will be of significance in respect of water permeability. Such forces present themselves, for example, if one end of a rod-shaped test piece is submitted to drying, while the other end is immersed in water. In such a case the passage of water through the material

will be conditioned both by the amount of free water and by a part of the half-fixed water.

### Risk of Cracking.

As a general definition of the risk of cracking the ratio between the tensile stress and tensile strength may be used, namely,

where  $R$  = risk value,  $\sigma$  = tensile stress, and  $T$  = tensile strength.

If the risk value is less than 1, the material can stand the tensile stress, while the condition is critical when  $R = 1$ .

If not otherwise stated, the following investigations and formulæ refer to rod-shaped elements which, in the state of tension, are firmly clamped at both ends.

As a result of cracking the tensile stress decreases and the material undergoes contraction. If, as an approximation, creep and similar phenomena are disregarded, Hooke's law may be applied to the relation between the tensile stress and the linear contraction which takes place when the tensile stress ceases. Consequently the risk value may also be formulated as follows:

where  $\Sigma$  = contraction per unit of length, and  $E$  = modulus of elasticity (under tension).

Expressed in words the relation implies the following rule: The risk of the occurrence of cracks is least when, simultaneously with high tensile strength, the material exhibits but slight specific linear contraction and a low modulus of elasticity.

With the help of the relation mentioned above between the modulus of elasticity and tensile and compressive strength (equation 1), it is possible to eliminate the modulus of elasticity in equation (3) and obtain

This implies the following rule: The risk of the occurrence of cracks is least if the material shows simultaneously slight specific linear contraction and a low ratio between compressive and tensile strength. This rule accords well with earlier experience.

By using Feret's approximate relation between compressive and tensile strength and making  $R = 1$  (to obtain the critical value of  $\Sigma$ ) it is finally found:

$$\Sigma = \frac{k_1}{T_1^{\frac{1}{2}}} = \frac{k_2}{E_2^{\frac{1}{2}}} = \frac{k_3}{C_3^{\frac{1}{2}}} \quad \dots \quad (7)$$

the consequence of which is that the material may show the greatest specific contraction when its mechanical strength is lowest, i.e., during the earliest stage of hardening.

*Temperature Differences as the Cause of Cracks.*—The temperature differences which are critical as regards the risk of cracks can be calculated from the following formula, where the conditions are the same as in the previous calculations :

where  $\Delta t$  = temperature difference.

$\alpha$  = linear expansion coefficient.

Table II gives figures referring to a Portland cement of good quality, from which it appears that the critical temperature difference for the hardened cement itself is about 25 deg. C., and that it is relatively little dependent on the

TABLE II.

Water-cement-ratio.	0.28.		0.40.	
Age, days (moist curing) .. ..	7	28	7	28
Tensile strength, lb. per sq. in. .. ..	820	828	498	580
Modulus of elasticity, lb. per sq. in. .. ..	2,640,000	2,720,000	1,390,000	1,970,000
Critical temperature difference, deg. C. .. ..	24.8	24.3	28.8	23.6

water content and age. (In the calculation  $a$  has been given the value 0.0000125.) Corresponding calculations for several different kinds of cement show that this figure is also relatively little dependent on the composition of the cement.

For a firmly fixed slab (a floor slab) a correction factor is necessary, in view of the fact that such a superficial layer is affected by tensile stresses in two dimensions:

where  $m$  = the reciprocal of Poisson's ratio.

As  $m$  may be given the approximate value of 7, it follows that the critical temperature difference is about 15 per cent. lower for the slab than for the rod. The corresponding hardened cement in the slab therefore tolerates only about 20 deg. C. temperature difference without cracking.

This condition of tensile stress is often shown by the occurrence of "star-shaped" cracks which form angles of 120 deg. with each other—that is, the simplest geometrical arrangement of cracks which permits of a general release of tension in one plane.

Of special interest is the temperature difference caused by the heat of hydration of the cement, as in mass concrete constructions with considerably more rapid cooling of the surface than of the inner core of the concrete. A preliminary calculation of the risk of cracks in the solid concrete pre-supposes the possibility of calculating the maximal internal temperature.

For two years a special cement has been made in Sweden for use in large concrete masses required in hydraulic structures. It is characterised, *inter alia*, by a specific heat development which is about 50 per cent. less than that of ordinary Portland cement. As regards the permissible heat development, this cement conforms fairly well with the special specifications which have recently been prescribed in the United States of America for cement to be used in the construction of certain dams, in addition to which the mechanical strength and the rate of its increase far exceed what is stipulated as a minimum in those special specifications.

*Drying as the Cause of Cracks.*—As has been mentioned, the drying of a hardened cement gives rise to shrinkage owing to the gel content of the material. These volume changes are considerably less noticeable in the outside dimensions of the concrete as the proportion of cement to aggregates in the concrete is reduced, because the sand and stone material, forming a stiffer skeleton in the mass, are practically not subject to such changes. On the other hand, in concrete which has an excess of cement mortar, shrinkage and swelling must be greater and may be considerable in very rich mixes in finishings, etc.

A simple method has been developed for a direct measurement of the tendency to crack due to drying. By this method, air of a certain relative humidity is made to pass round and along a rod of hardened cement which is clamped in a linear direction by being cast round a threaded iron rod. Owing to the fact that shrinkage stress cannot exceed the tensile strength, cracks occur in cases of great shrinkage, the frequency of which is characteristic of the material, and which corresponds to a risk ratio greater than 1. In Table III some typical experimental results are given, showing how the cracking frequency ( $n$ ) for a certain normal

TABLE III.

Water-cement-ratio.	Age in days of the specimen.	Relative humidity of the drying air.	$n$ .
0.27	7	70	8
0.27	28	70	9-9
0.27	7	0	11-12
0.27	28	0	12
0.40	7	70	7
0.40	28	70	10-10
0.40	7	0	11-11
0.40	28	0	14-14

Portland cement varies with the water content and age of the specimen, and the relative humidity in the drying air;  $n$  represents the number of cracks per 20 cm. of length of the rod.

The cracking frequency thus found is compared with the risk ratio calculated by (6) from the experimental determinations of drying shrinkage, compressive strength, and tensile strength, and the agreement may be considered to confirm the previous calculations. The magnitude of the experimental errors is due to

the fact that every point is based on no less than four different experimental determinations, whose divergencies may go in the same direction. With a suitable choice of length of the rod the number of cracks will be (within the limits of experimental error) in accord with the calculated risk value. It is striking that aluminous cement diverges from the Portland cements and does not agree with the theory.

#### Discussion.

Dr. W. H. GLANVILLE said experiments made at the Building Research Station on the relation between the crushing strength of 1:3 standard sand mortar mixed with a water-cement-radio of 0.32 and 1:2:4 concrete with a water-cement-ratio of 0.60 showed that the results for the various cements varied considerably, and that it was only possible to estimate concrete strength from a known mortar strength within very wide limits. Experiments with concrete with the same crushing strength and a 1:3 mortar mixed with a water-cement-ratio of 0.50 showed that in this case it was possible to estimate concrete strength from the mortar strength to within about 10 per cent. Also for these mixes the strengths were for all practical purposes the same. These experiments were in complete agreement with the authors' results.

Mr. B. HELLSTROM said that during the last decade or so investigations, particularly in Sweden, had made clear why deterioration took place in concrete dams when water percolated through. So far, however, a classification of the river waters in regard to aggressiveness had been lacking, and it was of interest to study Table I in the paper in which waters had been divided into groups depending upon the temporary hardness and the content of aggressive carbon dioxide. Although the figures referred to the effect of water on concrete pipes they could also be used for concrete dams. So far, great importance had been laid upon the *pH* value, but there had always been some doubt in his mind as to the reliability of using *pH* as the sole indicator of aggressiveness. Although the *pH* value was of some importance it should be used with discretion. Particularly for waters with very low temporary hardness and very low content of free carbon dioxide the *pH* value might vary between 8.0 and 5.0. If these extremely pure waters were disregarded, the *pH* value for waters under type II<sub>B</sub> would vary between 6.8 and 5.4. For example, there were waters with *pH* = 6.0 which could hardly be classified as aggressive, whilst others waters with *pH* = 6.8 might have a considerable degree of aggressiveness. So far as dams were concerned, the content of silt and solids in the water was a factor of great importance. In rivers containing much silt the deterioration of dams was never very marked, the reason being that even if the dams from the beginning were leaky the concrete had gradually silted up and become watertight.

Mr. W. H. WOODCOCK said in Fig. 2 the tests with most water gave the highest strengths, but, other conditions being equal, our experience was the opposite, and he would suggest that other reasons, such as difference in sand, accounted for the higher strengths. He agreed that wet mortars gave a better correlation than dry mortars with concrete. The relation between tensile and compression

strength was interesting, but so many factors entered into the question that many more cements must be tested before the formula could be accepted.

Water fixation in set cement was very difficult to determine, and the data supplied by the authors was insufficient. No temperature was given, and no indication of fineness or thickness of the layer of crushed concrete. With a thin layer and high temperature, one hour might be sufficient, but with a thick layer and low temperature, particularly if the air had a humidity of 97— as given in the paper under "free water"—3 months or even 3 years might be needed to dry the concrete to constant weight. The temperature the authors used could not be very high for they treated chemically combined water and adsorbed moisture as one, and had made no attempt to separate them.

The calculation of strength from the solid phase was not very clear. The amount of combined water would certainly give some idea of the hydration of the cement, and hence was related to the strength, but the adsorbed moisture was dependent on surface as well as other factors, and other things being equal a large amount of adsorbed moisture meant a large amount of surface in the interior of the concrete, which suggested weakness instead of strength. For this formula it was essential to separate combined water from adsorbed moisture.

The authors had stressed the importance of the quantity of heat evolved in setting, and had given an interesting graph on the relation between the rise of temperature, number of calories evolved, and water ratio. Unfortunately they had not included that most important factor the dissipation of heat, and their statement "on the presumption that the loss of heat can be neglected" before the temperature calculation was made, might lead some to think that heat dissipation could be neglected, whereas it was one of the chief saving factors in concrete of ordinary thickness.

A simple but fairly exact determination of temperature rise could be obtained by the use of an ordinary thermos or vacuum flask, and if the heat equivalent of the flask were determined it was possible to make an approximate determination of the number of calories evolved from any given cement sufficiently accurate for all except research and similar work.

The method devised by the authors for determining the liability of cement to form cracks was ingenious and should prove useful. Here again further particulars of the method would be helpful as, in addition to the relative humidity of the air, the velocity and temperature would play an important part. Testing cement for liability to develop cracks had not come into general practice, except possibly in the form of pats, and the authors had done well in suggesting their method, but they did not appear to have taken into consideration the full effect of "creep."

Possibly the most surprising statement in the paper was that Swedish engineers considered water with one grain per gallon of carbonic anhydride in solution, and a hardness of anything over  $2\frac{1}{2}$  deg., to be practically harmless. In this country a water of 3 deg. hardness would be considered soft, and by no

means harmless if percolating through concrete. The authors drew a distinction between the effect of waters containing a large proportion of carbon dioxide in solution and those containing little or none. It was true that after the free lime in the concrete had been fully carbonated any carbonic anhydride which might be present in the water would have a dissolving action, but until the lime had been carbonated, i.e., while the free lime was still there, the effect of the carbonic anhydride would be to fix the free lime, whereas water free from carbonic anhydride would dissolve it. As lime in the interior of thick concrete had very little opportunity of carbonating except with the carbonic anhydride brought in by percolating water it was possible that under many conditions soft water free from carbonic anhydride would be more dangerous than water containing carbonic anhydride.

Mr. S. G. S. PANISSET said that a cement manufacturer had three ambitions, of which the first was to make a cement which would attain the strength of granite in six hours. The advantages of such a cement were obvious, but of late years discussions regarding the development of heat in large masses of concrete had given rise to doubts as to whether a cement reaching its ultimate strength in six hours would not develop so much heat in the process as to cause disturbances in large mass work.

The next ambition was to make a cement containing no more than 50 per cent. of lime. To a chemist it was irritating to be forced to incorporate 63 per cent. of lime in Portland cement when the first thing that happened during setting was that nearly one quarter of it was dissociated and became an inert constituent of the concrete, or even in some circumstances an undesirable constituent. There was an opportunity for research work in seeking means of rendering low-limed combinations of silica and alumina active without the present procedure which led to the presence of free lime in set cement.

The last ambition was to produce concrete that would not crack or craze ; he emphasised that the reference was to concrete, and not to cement, because he thought that the responsibility for the cracking and crazing of concrete lay as much, or even more, with the aggregate and water than with the cement. The fact that concrete slabs moulded under sufficient pressure to eliminate excess water did not craze was a clear indication of where the fault was to be found, and engineers could do much to improve matters by controlling the shape and size of the constituents of the aggregate used in concrete.

He welcomed the possibility of having one simple test to indicate the strength of cement when embodied in a concrete, but if any such tests involved the publication of apparently reduced tensile strengths it should become an international standard, otherwise the nation first standardising such a test might be handicapped in exporting cement with tests giving lower figures than customary although capable of reasonable explanation.

With regard to heat evolution, the special cements advocated, more particularly in America, appeared to be obtained by a retrograde movement in regard to strength, and he considered that a better aim would be to control the

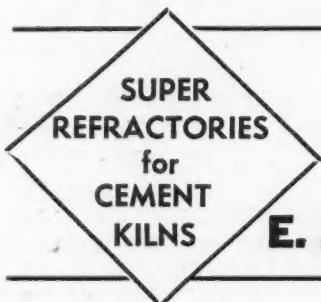
rate of development of heat. It had been insisted that high strength was unnecessary in connection with large concrete mass work, and it still might be possible for engineers to obtain low heat development by incorporating in the concrete a proportion of fine inert powder and so avoid the necessity of preparing a cement of deliberately reduced strength.

With regard to the solvent action of certain waters, notably upon the free lime content of set cement, the remedy at present available was the addition of trass or pozzolana. He much preferred artificial pozzolana made by the calcination of suitable clay at definite temperatures; such a pozzolanic material of controlled properties was superior to one dug from the earth. Even pozzolana, however, did not reach the ideal because the interaction between the lime set free during setting of cement and the pozzolana was slow; the ideal to be sought was the addition of a material which would interact with the lime as soon as the latter was formed.

Mr. CARL PONTOPPIDAN said the desire for a cement with low heat properties and low shrinkage was justifiable, and he believed the cement industry was willing to meet the demand for such cements. However, there must be a standard to work by, and it must be known what was meant when heat of hydration and shrinkage were specified. He had found that it was not possible to calculate the heat of hydration from Wood's formula. There is a very wide deviation in a number of cases between the calculated and the found amount of heat.

Dr. Werner and Dr. Giertz-Hedström proposed a formula for determining the resistance of concrete against the formation of cracks due to shrinkage. In this formula entered the strength of the concrete, but the strength was determined by water storage of the concrete specimens. This appeared somewhat irrational. Shrinkage was a phenomenon caused by the drying out of the concrete specimen (combined storage), and it would seem to be more rational to express the forces which resisted the shrinkage as strength found by combined storage, i.e., under conditions giving rise to shrinkage. By using the strength of water-stored specimens other conclusions might be arrived at than by using strength after combined storage.

Messrs. T. Halcrow and S. Bylander also took part in the discussion, to which the authors replied.



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*Refractory Standard 3250° Fahr.*

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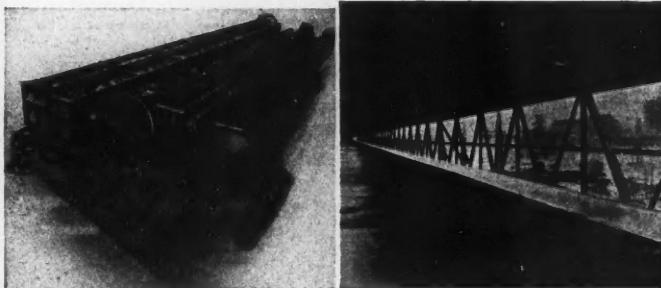
## New Swiss Specification for Cements.

THE new Swiss standard specification (1933) for Portland and other cements is a distinct departure from current practice in regard to strength tests. Bars of mortar are first tested for flexion (transverse strength) and the two broken parts of each bar are then tested for compression.

A summary of the specification for Portland cement is as follows : Maximum limit for insoluble plus  $\text{CaCO}_3$  plus  $\text{CaSO}_4$ , 10 per cent. Maximum limit for insoluble plus  $\text{CaCO}_3$ , 5 per cent. Maximum limit for  $\text{SO}_3$ , 2.5 per cent. Maximum limit for  $\text{MgO}$ , 4 per cent. Maximum limit for residue on 4,900 meshes per sq. cm., 10 per cent. Maximum limit for Le Chatelier test, 8 mm. Minimum limit for initial set, 2½ hours. Minimum limit for final set, 7 hours. Minimum limit for flexion strength (3 sand 1 cement), 7 days, 35 kg. per sq. cm. Minimum limit for flexion strength (3 sand 1 cement), 28 days, 45 kg. per sq. cm. Minimum limit for compression strength (3 sand 1 cement), 7 days, 180 kg. per sq. cm. Minimum limit for compression strength (3 sand 1 cement), 28 days, 275 kg. per sq. cm.

The Le Chatelier limit includes the expansion during 24 hours cold water storage as well as during 2 hours boiling. Tolerances of 30 per cent. are allowed

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on the chemical composition limits, of 10 per cent. on the strength limits, and of 25 per cent. on the fineness limit. The bars for flexion and compression tests are 16 by 4 by 4 cm., and 11 per cent. water is used for gauging. Bars made in accordance with the specification should weigh 562 grammes. Transverse strength is obtained by multiplying the breaking load by 0.234. The setting time test is on cement gauged for three minutes to normal consistency (Continental standard).

In addition to the specification limits mentioned there are given supplementary data as follows: (1) The specific gravity of cement is from 3.0 to 3.2. (2) The usual loss on ignition is between 2 per cent. and 5 per cent. (3) The hydraulic modulus averages 2.0. (4) The rise in temperature in the centre of a bar of neat cement measuring 10 by 10 by 50 cm. ranges from 10 deg. to 25 deg. C. Curves are given showing the contraction of similar bars of neat cement and of 1 to 6 mortar after 90 days.

For high-strength cement (equivalent to British rapid-hardening Portland cement) the strength requirements are as follows. Minimum flexion strength (3 sand 1 cement) at 3 days, 40 kg. per sq. cm. Minimum flexion strength (3 sand 1 cement) at 7 days, 50 kg. per sq. cm. Minimum flexion strength (3 sand 1 cement) at 28 days, 60 kg. per sq. cm. Minimum compression strength (3 sand 1 cement) at 3 days, 250 kg. per sq. cm. Minimum compression strength (3 sand 1 cement) at 7 days, 340 kg. per sq. cm. Minimum compression strength (3 sand 1 cement) at 28 days, 420 kg. per sq. cm.

The booklet containing the Portland cement specification (published by the Société Suisse des Ingénieurs et des Architectes) also contains specifications for aluminous and natural cements and for lime and gypsum plaster.

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